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GEOLOGY

ITS INFLUENCE ON MODERN BELIEFS

4-34

Being a Popular Sketch

of its

Scientific Teachings and Economic Bearings

BY

DAVID PAGE, LL.D., F.G.S.

AUTHOR OF TEXT-BOOKS ON GEOLOGY
AND PHYSICAL GEOGRAPHY

WILLIAM BLACKWOOD AND SONS
EDINBURGH AND LONDON
MDCCCLXXVI

GEOLOGY

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NOTE.

THESE Lectures were prepared last winter for the members of the Edinburgh Philosophical Institution, but illness prevented their delivery. Feeling still uncertain as to their *vivâ voce* production, the Author presents them in published form—believing the subject of general interest, and not the less so that it is treated in a brief and popular form. Many can find a leisure hour for the perusal of a handy sketch, who could not possibly command time for the study of an exhaustive treatise.

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AND ECONOMIC BEARINGS

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GEOLOGY:

ITS INFLUENCE ON MODERN BELIEFS.

I.—GEOLOGY: ITS SCIENTIFIC TEACHINGS.

EVERY subject worthy of the name of Science presents itself, or ought to present itself, in two main aspects; one theoretical, and appealing to the intellect and reason—another practical, and applicable to the industrial purposes of life. It may be long before the theoretic conception shape itself into practical utilities, and the one may be intimately studied without reference to the other; but science becomes doubly valuable when, exciting our intellectual interest, it can add at the same time to our physical comforts. In this respect Geology stands pre-eminent, and no branch of knowledge, perhaps, has more direct claims on our consideration, whether in its scientific or economic aspects. As a science, it seeks to unfold the history of our planet—what is its composition, how were its rocks and rock-formations produced, what are the changes they have undergone, and are still undergoing; what the nature of the vegetable and animal remains they entomb; and generally, what were the conditions and aspects of the world at the successive stages of its history. As the geographer depicts the present aspects of land and water, with all their varied garniture of plants and animals, so the geologist seeks to portray the past conditions of the globe—his science being not inaptly described as "the physical geography of former ages." In unravelling this history, the student has much to observe, much to note and compare, and much to deduce; his problems requiring not only extensive and varied knowledge, but severe and accurate discrimination. Here, then, is the scientific side of Geology—dealing with physical change, time, vital progression, cosmical order and law—evolving a history which startles alike by the strangeness of its details, the endless variety of its incidents, and the inconceivable lapse of its duration.

Nor is the science of less importance in its practical bearings, seeing how much man is dependent on the mineral and metallic treasures of the earth for his mastery over the forces of nature. His stones for building and decoration, his fuels, his lighting materials, refractory substances, pigments, gems, and precious stones, metals and metallic ores, are all derived from the earth; and as these substances are not scattered broadcast through the rocky crust, it is the province of Geology to determine where they occur, how they occur, in what abundance they occur, and with what facilities they can be obtained. The Strathearn Coal Company, notwithstanding all its persistent enthusiasm, cannot call coals from the vasty depth of the Old Red Sandstone; a legion of Fifeshire miners could not extract a single grain of gold from the limestones of the Western Lomonds; nor need any of my audience expect to grow rich by investing in any company whose object is to extract tin-ore from the heights of the Borough-Moor. Considering, therefore, the power with which man has been invested by his knowledge of the minerals and metals, in all that relates to his tools, implements, machinery, structures, ornamentation, and locomotion, the science which directs him to those minerals and metals can never fail to hold an important place in his study and estimation.

To indicate the scientific and economic bearings of this science is the object of the present lectures. I say *indicate*, for little more than a mere indication of such a subject can be given in a couple of evenings, and for this purpose I shall endeavour to be as plain, precise, and methodical as the matter will permit. Without such a course, much of my lecturing would be useless, and your time in a great measure wasted. I would rather that some of my audience should say, "We knew all this before," than that any should go away without a satisfactory understanding of the facts I have to communicate.

I. Perhaps the most intelligible course I can follow is to indicate, in the first place, the scientific teachings and beliefs of the science, and then proceed to its economic aspects as bearing on the arts and industries of civilised life. In this way, the theoretical and practical will run no risk of being confounded, and those who take little interest in the one may give their undivided attention to the other. As a science, then, the first great teaching of Geology is, *that the crust of our globe is undergoing incessant change, or in other words, continuous waste and reconstruction of its materials.* The gases and moisture of the atmosphere are ceaselessly weathering, the frosts disintegrating, the winds drifting, the rains softening and removing, running water cutting out channels and transporting, waves battering, and tides and ocean-currents carrying and reconstructing the eroded materials. Nor are the solid waters less active than the liquid—the glacier is ever rasping and gouging and deepening the mountain glen; the iceberg and icefoot ever bearing away abraded rock-matter to the depths of the ocean. What liquid water is impotent to remove becomes an easy burden to the solid in the form of floating ice. Chemically, the waters which percolate the crust are always dissolving and bringing to the surface, there being no such thing as absolutely pure water issuing from the earth—every spring bearing its quota of lime, of silica, of iron, of salt, or of some other mineral ingredient. Nor is it otherwise with vital agency. The plant is building up carbon from the air in the form of peat-moss, swamp-growth, or jungle-growth; the animal is secreting lime and silica from the waters in the shape of coral-reefs, shell-beds, foraminiferal deposits, and sponge-growths. Every agency—mechanical, chemical, and vital—is busy at work wasting, reconstructing, and transforming the exterior surface; while from the interior the volcanic forces, in their manifestations of volcano, earthquake, and crust-motion, are as constantly throwing the rocky crust into new forms of diversity and irregularity. There is no such thing as permanence for the terraqueous surface. Hills have been worn down, valleys eroded, lakes silted up, deltas accumulated, sea-beds shoaled, mountains piled up by volcanoes, new islands raised, and old lands submerged beneath the waters. And this not once, but over and over and over again—every stratified formation bearing evidence not only of the water-area in which it was deposited, but at the same time of the dry lands from which its materials were eroded and transported. Our forefathers were aware of local and limited changes; they could not shut their eyes to the wearing away of sea-coasts, the convulsions of earthquakes, the upthrows of volcanoes, and similar phenomena; but of the universality of terraqueous change they had no adequate conception. Olden belief sang of the earth's stability; modern philosophy sees no unmoved foundations, no everlasting hills, no set bounds to the ocean.

There rolls the deep where grew the tree;
O earth, what changes hast thou seen!
There where the long street rolls, has been
The stillness of the central sea.

The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mists, the solid lands—
Like clouds they shape themselves and go.

Feeble as the agents of change may seem, slow and gentle as may be their operations, their action is incessant and irresistible, and capable, in course of ages, of producing the most gigantic results. It is not so much a matter of force as of time: the falling drop hollows the hardest stone; organisms invisible to the naked eye can pile up reefs of colossal dimensions.

Such is the first great scientific teaching of Geology: the terraqueous surface of our globe ever changing; rock-matter ever suffering transformation in place and condition; nothing taken away—nothing added, perhaps, save a few stray meteorites which have now and again come within the sphere of our planet's attraction. Every rock-formation can trace its descent to some pre-existing formation, just as future formations shall trace their origin to those now existing around us. How startling these incessant changes! how marvellous the transformations the terraqueous surface has undergone, and is still undergoing! Old rock-matter worn down, and renovated, as it were, by the baptism of the waters, again to be upheaved into dry land, again to be submerged, and this alternation apparently as illimitable in the future as geology has shown it to have been in the ages that have passed away!

II. The second teaching of our science is,—*that the forces producing these changes are incessant in their operations and uniform in their modes of action, and that there is no foundation for the olden beliefs in catastrophes and cataclysms beyond those of a local and limited nature.* In other words, when interpreting the history of the past, we are not entitled to call in other forces than those now operating around us. These forces, be it observed, all owe their origin to the earth's relations to the solar system, and must be regular and enduring as that system is regular and enduring. Not a shower that falls, not a breeze that blows, not a wave that strikes, nor a tide that flows, but owes its origin, directly or indirectly, to the planetary relations of the earth. The unequal heating of the atmosphere by the sun's rays, for example, produces winds, winds waves, and waves degradation on every rocky shore; and as with this instance, so with every other terrestrial phenomenon. They can all be traced back to the earth's planetary relationships. Life is altogether dependent on solar heat, and even the internal fire-forces of our globe are in all likelihood the residual phenomena of some primal solar connection. If, then, the forces that now act be regular and uniform, and productive of certain results, we are entitled to assume that they were the same, and productive of similar results, in former ages. On this rests the whole superstructure of geological reasoning. We reason from the present to the past; from formations now taking place around us to those which constitute the masonry of the rocky crust. If the forces are not similar we cannot compare their results; if we give way to catastrophes and cataclysms, the history of the past becomes a mass of uncertainty and confusion.

And herein lies the wide difference between olden and modern opinion. Formerly, every ravine, precipice, and islet abruptly separated from the mainland, was the result of some convulsion of nature, though clearly, to modern geology, the slow and gradual product of erosion and denudation. So frequently, indeed, was this convulsionary condition of nature appealed to, that had nature not been endowed with a very different constitution, she must long ere now have expired of convulsions.

It is true, the throes of the earthquake, the outbursts of the volcano, and the sweep of the flooded river, are cataclysmal in their nature; but they are merely local and limited phenomena, and never interrupt or interfere with the general cosmical order. There may also be great cyclical changes, occurring at widely distant periods, that may modify this uniformity of things; but the modifications are so gradual, and the intervals so vast, that to us the continuity of nature is virtually unbroken.

No doubt, the forces may act with greater intensity in one area than another area, and at one period than another period; but though differing in quantity, the quality of their action is still the same. Thus, the conditions of a country may give rise to greater rainfall, and heavier rainfall give birth to larger rivers; and larger rivers will do a greater amount of geological work in a given time, but the work differs only in degree, and not in its essential nature. The amount of erosion and denudation will be greater, but the nature of the erosion will be the same. Even the admission of a gradually cooling globe scarcely interferes with this idea of uniform action, the process being so slow that æons must pass away before there can be any sensible diminution of the manifestations of vulcanicity as at present experienced.

Armed with this belief in the continuity of nature's operations, and abandoning all ideas of "mountain upheavals," "continental convulsions," "oversweeping waves of translation," "universal deluges," and the like, the geologist can reason from existing appearances to those occurring in the rocky crust, and can thus work out a history of the globe with greater or less certainty as these appearances are legible or obscure. Frosts, rains, waves, and running water obeyed the same laws in former ages as at present, and were productive of similar results; the ancient coral zoophyte constructed its calcareous home upon the same principle and by the same process as its modern congeners of the Pacific; and even the volcano and earthquake disrupted and accumulated, upheaved and submerged in past times, much as they do at the present day. Every formation contains within it some indications of its origin. The earth always retains traces of her former operations and aspects—writes her own history, in fact; and this history it is the task of the geologist to interpret.

III. And this brings us to the third teaching of our science—namely, *that as similar results arise from similar causes, if we understand the formation of rocks at the present time, we shall be enabled to account more or less satisfactorily for the origin of the various rocks and rock-formations which constitute the solid crust.* In other words, we shall see that this crust has been built up by existing forces, and the work of ages, and not, as formerly believed, an act of sudden or instantaneous creation. Everything retains something of its growth and being, and the earth has kept with jealous care thousands of traces of her former operations, aspects, and conditions. It is not merely that we have strata evidently deposited in water, but strata which show that they have been laid down respectively along shore, in shallow and in deeper waters, and even that these waters were lacustrine, estuarine, or marine. As conglomerates are but agglutinated pebbles, sandstones consolidated sands, and shales compressed muds, so conglomerates bespeak exposed pebbly beaches, sandstones open shores, and shales deeper and stiller waters. Limestones tell of coral-growths, shell-beds, and foraminiferal deposits—the chalk of our downs being but an earlier accumulation of calcareous sea-ooze, similar to that of the Atlantic sea-bed, and elaborated by analogous forces. Coals speak of forest-growths, peat-mosses, and swamp-growths; and not a rock in the old trap hills around us but finds its counterpart in the lavas, scoriæ, bombs, and agglomerates of Vesuvius and Etna. Still further, as at the present day plants and animals are drifted from the land and entombed in sediments, buried where they grew, or are carried and water-logged far from their native habitats; so in the old sedimentary rocks the geologist finds the petrified remains of roots, stems, leaves, fruits,—of corals, shells, bones, teeth, scales, and other organisms, all indicating more or less distinctly the tribes to which they belonged, and the conditions under which they existed. Even evidences, physical and physiological, more evanescent than these have been preserved to us, so loath does nature seem to obliterate all traces of her handiwork. The ripple of the ebbing tide, the mud-crack caused by the summer sun, the patter of the rain-drop, the trail and burrow of the worm, the print of the passing foot, the coprolite with its undigested scales and crusts, even the colour-bands of the sea-shell, have been preserved to the eye of science, telling of sun and air, of beauty and motion, of life and death, even as the same things tell their tale and register it at the present day. Take, for example, your own Burdiehouse limestone. Not only does it contain evidence of its deposition in fresh water, of the vegetation that clothed the landscape, and of the life that thronged the waters, but its coprolites show that one form of life preyed upon other forms, and even the peculiar species on which they preyed.

In fine, the strata of the rocky crust are but the leaves of a great record, each impressed with characters which tell so much of the geographical conditions of the period; and by reading them in sequence, Geology has furnished an outline of Earth-history—sketchy and imperfect no doubt—but sufficient to show how frequent the changes she has undergone, how varied the aspects she has assumed, and how vast the time she has circled in obedience to the laws which still continue to govern. We say *by reading the strata in sequence,* for there can be no connected history till the stratified systems have been arranged in chronological order, from the oldest we can discover to those still in process of formation. And it is this slow and orderly building up of the rocky crust which constitutes the third teaching of Geology, in contradistinction to the olden notion of its instantaneous agglomeration from a state of chaotic confusion. Whatever may have been the origin of the globe, the rocky crust which forms the theme of the geologist has been a thing of slow and continuous growth—ever changing its aspects, but ever retaining within its structure sufficient to show the forces by which it has been gradually built up and moulded into its existing form.

IV. While arranging the earth's crust into consecutive systems and formations, Geology has determined in the fourth place, *that certain rocks and minerals are peculiar to certain formations, or at least occur in greater abundance in some formations than in others.* This determination belongs to the economic side of our science, and will be specially treated in next lecture, but we note it in the meantime as a teaching which has exercised a most beneficial influence on olden opinions. Formerly, coals, gold, iron, and other minerals and metals were sought at random, and large sums often spent in exploring localities where a knowledge of geology would have told the search was fruitless. Men need not search for the veined marbles of the metamorphic rocks in tertiary beds, for metalliferous veins in secondary strata, nor for workable coal-seams in the Old Red Sandstone and Silurian systems. This determination is of vast economic importance, and, as will be fully seen hereafter, has given a certainty to practical operations, altogether unknown to our forefathers. And this certainty will extend, as geology continues to map out with greater precision the boundaries of the respective formations, and to ascertain with accuracy the alternations and thickness of their strata. Systematic surveys are of recent origin, and half a century has scarcely passed since nations began to perceive how essential they were to the development of their mineral and metallic resources. The world's wealth will never be known till every accessible portion has come under the examination of the geologist. Then, and not till then, will nations learn to direct their attention to the accessible and abundant, instead of wasting their energies on the scantily-developed and inferior. That is the true economy which produces the greatest results with the least amount of labour.

V. Having arranged the stratified formations in chronological order, and having read all that can be read of the facts they disclose, the fifth great teaching of geology is, *that the time involved in the production of these facts and formations is vast beyond human conception, and can only be spoken of relatively and not absolutely in years and centuries.* Our fore fathers believed in the recentness of the earth. Geology has established, if it has established anything, that it has existed under varying terraqueous conditions for untold ages. It is not only that the various formations of the crust are of vast thickness, and that each bed shows slow and orderly deposition in water, but that the matter of which these beds are composed has had all to be worn, and wasted, and transported, particle by particle, from pre-existing rocks. Many beds, again, are formed wholly of vegetable and animal organisms, and as these lived, and grew, and died, generation after generation, each bed—to say nothing of a succession of beds—must have taken long years for its increase and accumulation. Further, many formations have been completed, consolidated, converted into dry land, and subsequently submerged ere the overlying formations were deposited upon them; and all this—reasoning from the rate of action now prevailing—must have taken ages upon ages for its accomplishment. Still further, as the mountains and mountain-chains of the globe are of widely different ages and often of vast dimensions, these mountains, whether of volcanic accumulation or of circumdenudation, must have taken long epochs for their elaboration. Everything, in fine, in the solid crust, whether of mechanical, chemical, vital, or igneous formation, bespeaks at the existing rate of operations an inconceivable lapse of time—time for which we have no measure in years, but can only dimly indicate by speaking of ages, and epochs, and cycles.

We cannot shorten this time by calling in revolutions and abnormal conditions. The very rocks lift up their voices against such an outrage on their origin and formation. The particles of a sandstone, for instance, speak of their gradual attrition from pre-existing rocks; its laminations tell of orderly deposition; and its fossil remains unmistakably prove that they lived and grew by degrees, just as plants and animals live and grow and come to maturity around us. The fossil trunk shows its rings of annual growth, the fossil shell its lines of yearly increment, and both plants and animals occur in all stages of growth, from the embryo to the full-grown individual. There has been no other course for nature in the past than that which she follows in the present. In the successive formations, from the Cambrian up to those of the present day, there has been no suspension of her laws, no break in the continuity of her operations!

How much older the Old Red Sandstone is than the new, or how long the Carboniferous system took for its formation, the geologist cannot tell. To him time is merely relative; he believes that one formation is older than another, but how much older he cannot say; he believes that some formations took longer time for their accumulation than others, but how much longer he cannot determine. To him everything involving time is merely relative, and as to the gross amount, he can form no conception, any more than the gazer can form of distance by looking into the depths of the celestial blue. He is in the habit, however, of speaking of *historical*, of *geological*, and of *pre-geological* time: meaning by historical all that is embraced by authentic history; by geological, as far back as the rocks give evidence of their modes of formation; and by pre-geological, all that preceded the stratified rocks, and of which the crust gives no evidence of the conditions under which it existed. Historical time is but a beat of the pendulum compared with the epochs with which the geologist has to deal; but to historical and geological time he restricts all his reasonings, leaving pre-geological time to the physicist, astronomer, and cosmogonist, who may frame what hypotheses they choose respecting the primal conditions and origin of our planet. These, though not uninteresting to him, lie beyond the boundaries of his science, which restricts itself to the rocky record; and where this becomes illegible he closes the book, declining to guess where he cannot decipher, and ceasing to assume where he has no groundwork for legitimate deduction.

Such is time to the geologist—a thing which cannot in the meantime be expressed in years and centuries, but only indicated relatively in periods of longer or shorter duration. It may happen, however, in the future of the science, that the recurrence of certain events, such as the glacial epoch, may be found of secular return and dependent on calculable astronomical data, in which case an approximation may be made to the duration of some portions of geological time; but we can never hope to arrive at the sequential dates of the whole of the stratified formations. This much we know, and what no well-informed mind now attempts to gainsay, that our world is of incalculable antiquity, geologically speaking, and may have existed myriads of years before the stratified rocks began to bear evidence of the forces by which, or the conditions under which, they were respectively produced. To accept the 7000 years of the olden chronology would be at once to distort every fact, and destroy every inference of legitimate geology. The sedimentary systems, with all their alternations of strata, their vast thickness, their successions of organic remains, and their repeated submergences and upheavals, cannot be crushed into any measurable limit of time; and any attempt to do so leads only to absurdity and confusion.

VI. Having received from Geology these facts of change, force, uniformity of action, and time, the next great teaching of the science is, *that numerous as are the forms of life, vegetable and animal, now peopling the globe, they constitute but a small fraction of the life which has successively appeared and passed away.* It is not that myriads of the same species and genera which now flourish around us have lived and died during the geological epochs, but that myriads of forms differing in species and genera, and even in family and order, from those now existing, have successively appeared, multiplied, spread, and then become extinct to return no more. The very rocks, in many instances, are made up of their remains—plant and animal, aquatic and terrestrial, herbivorous and carnivorous,—the whole testifying to a scheme of life differing specifically and stretching away into the illimitable past, but subject to the same conditions which still control the propagation, growth, and dispersion of existing life-forms. Our forefathers knew that life and death had been coeval with the world; but to them it was the life and death of the forms they saw around them, and not of other forms differing widely in features and functions. This knowledge of extinct life is altogether due to geology; and numerous as are the forms which have been discovered, they are, in all likelihood, but a mere indication of what has yet to be exhumed from the rocky crust. Under the teachings of Geology, Biology assumes a new and nobler aspect, and the botanist and zoologist have now to deal with a system of life, though infinitely more extensive and varied, yet in reality more homogeneous and intelligible in its plan and development. Any truly philosophical scheme of biology must henceforth embrace not only the living, but the extinct, so far as they have been discovered—the living enabling the palæontologist to interpret the extinct, and the extinct throwing light on the affinities and development of the living. And here it may be observed, that our natural history museums will never fulfil their functions aright, till they have marshalled in one line of life the extinct with the living—showing the period at which any form made its appearance, and the various modifications it has undergone till the time of its final extinction. Then, and then only, will the affinities between the living and the extinct become apparent, and the course of development through which the various orders have passed be made plain and palpable.

This enlarged conception of Life, with all its multifarious forms and intimate interconnections, is altogether the result of geological research; and though the science had done nothing more, this would have been amply sufficient to have stamped it as one of the most important departments of natural knowledge. Our forefathers drew their arguments of design from existing forms, and dwelt with wonder on the coadaptations of the vegetable and animal economies; how much more would their argument have been strengthened and their wonder increased had they known of these fossil forms, and that the same harmonious coadaptations had prevailed for untold ages? It is one thing to witness the fatherly care of the Creator in the present; it is another thing, and one that may teach us humility, to learn that the same fatherly care was as tenderly bestowed on the lower animals, thousands of ages before man came into existence. How wide the difference between olden and modern Biology! the one restricted to existing forms, the other embracing not only the living, but all that Geology has discovered or may yet discover in the crust of the globe; the one merely describing and enumerating living species, the other striving to determine the relations that bind the existing and extinct into one harmonious and ever-evolving plan.

VII. Startling and impressive as has been the discovery of this long line of extinct life, it is equally interesting to learn from geology, in the seventh place, *that there has been a gradual ascent in time from lower to higher forms: in the vegetable kingdom, from the cellular to the vascular, from the flowerless to* *the flowering, from the monocotyledonous to the dicotyledonous; and in the animal kingdom, from the invertebrate to the vertebrate, from the fish to the reptile, from the reptile to the bird, and from the bird to the mammal.* All that has yet been discovered confirms this ascent; and though there are avowedly many gaps to be filled up, nowhere has there been anything detected to interfere with the conclusion that there has been a gradual evolution from lower to higher forms of vitality. The precise period at which the higher form first makes its appearance may not, in every case, be determined, and the geologist, in the course of discovery, may have to alter his opinions on this and other topics of detail; but the broad fact of "an ascent in the main," as Professor Owen terms it, stands unchallenged and unchallengeable.

Of this vital progression our forefathers had no certain knowledge. They knew there were lower and higher forms in existing life; but that there had been an evolution in time, in harmony with this gradation, they were altogether ignorant. Call it evolution, development, creation, or what we will, it is clear it must have been brought about by some process or other, and the nature of that process is one of the highest problems that can engage the legitimate efforts of philosophy. The origin of Life may ever lie beyond the human comprehension; but the manner in which it has manifested itself, the course it has run, the variations it has undergone and is still undergoing, and the proximate causes of these variations, are subjects not only of legitimate inquiry, but of hopeful solution. The outcry against theories of development may interrupt and annoy, but it can never prevent philosophical speculation as to the means the Creator has employed to vary the Life of the globe, or to introduce higher and higher forms at the successive stages of geological history. The solution may be hard to reach, and men may long feel themselves "like children crying in the darkness, and with no language save a cry;" but the incentive to inquire is irresistible; and, after all, the human mind is simply following the natural bent of its constitution when it seeks, not merely to observe phenomena, but to ascertain the causes by which they are produced in orderly sequence and interconnection.

Whether science shall ever be able to determine the proximate causes of this progression, time alone can tell; but in the meanwhile, Geology, believing in the operation of natural law, does right in seeking the solution among the forces by which Life is now sustained and undergoes modification. We see variation taking place around us, and this partly owing to geographical position, partly to climate and food, partly to the struggle for existence, partly to heredity, and, it may be, to other unknown factors acting in obedience to a great law of evolution; and if, in dealing with inorganic nature, we reason from the present to the past, are we justified in adopting any other method in dealing with the organic? During the present century, science has marvellously extended the knowledge of nature's methods, and who shall set limits to her future acquirements? It has been strikingly said, "The broader the circle of light, the wider the margin of darkness that surrounds it;" but it is equally true, the more we can broaden the light, the more of that darkness we dispel.

VIII. If, then, there has been an ascent from lower to higher forms of vitality in the past, and the forces which have been the concomitants or the causes of this ascent be still in operation around us, the fair presumption, in the eighth place, is *that a kindred ascension will mark the course of the future.* We see no decline in the forces by which the rocky crust is wasted and reconstructed; new formations are being elaborated now as they have been in all former ages; life multiplies and spreads as it ever did; and there is no symptom whatever either of completion of the vital scheme, or exhaustion of creative energy. As life has slowly, and gradually, and through long epochs, passed from lower to higher forms, the legitimate inference is that it will still continue to ascend, and is in fact in process of ascension, though the rate be so gradual as only to be perceptible after the lapse of ages. Biologically speaking, the course of creation has been ever onward and upward; shall it not be onward and upward still? As far as science can trace the order of creation, the course seems to have been from matter to mechanism, from mechanism to life, from life to mind, and from mind to morals; and who, looking at man's limited powers and imperfections, shall dare to set bounds to its further development and ascension?

On the contrary, everything, somatically and mentally, tends to confirm the belief in man's progression, and points to a time when his successors, in the ascensive direction, shall as far excel him as he now excels the forms that stand next beneath him in the scale of vitality. Nothing stands still. Nature never repeats herself. That which has been, will never recur again; and if things occasionally seem to revolve in a circle, it is not a circle on the same monotonous plane, but a spiral of higher and higher ascension. Nor does this progression affect merely life and mind; it permeates the whole of Humanity, social, moral, and religious. Nothing, indeed, stands still, and the teachings of history are lost upon us if we fail to perceive the advancement. To stand still is to die—to go forward is to live and grow. Let us cheerfully accept the divine ordinance.

> Forward! forward! let us range;
> Let the great world sweep for ever
> Down the ringing grooves of change.

How hopeful and inspiring this faith in the onward and upward development of creation, compared with the olden beliefs that were ever bewailing man's innate tendency to decline, and ever predicting the speedy termination of all things terrestrial!

How fortifying, though overwhelming, the idea, to look forward to a world whose end we cannot fathom any more than we can trace its beginning! How ennobling to believe in the onward and upward development of life and mind—the finite ever drawing nearer to the infinite, and yet like those mathematical lines which, though ever approaching to each other, can never meet!

IX. This belief in the onward and upward progression of life receives the strongest confirmation from the history of man himself, and this forms another great teaching of our science. So far as geology has discovered—and her researches have been extended to both hemispheres—*man's beginnings have always been of a rude and lowly nature.* A dweller in caves and wigwams, a hunter and fisher, with tools and implements of wood, bone, and stone. A naked savage, or at best clad in skins, living on fruits, roots, and the produce of the chase, and not unfrequently addicted to cannibalism. No perfection from which to fall, but a higher and higher state to which he may hopefully aspire. Such are his beginnings in every country explored by geology; and his rise has been successively through ages of stone, bronze, and iron. The course of civilisation, even under the most favourable circumstances, has ever been slow and gradual—often checkered and irregular—but though checkered it has been ever advancing.

Mankind, too, has been ever evolving, under the great law of ascension, into higher and higher types. History is but a record of the progress and spread of the higher race, and the decline and extinction of the lower in the struggle for existence. Sentiment may drop a tear over the fate of the Red Indian, the Australasian, and the New Zealander; but reason, convinced of the great law of ascension, accepts and submits to the decree. This law has been operative in the past, as proved by geology and history; it is operative at present, as we perceive around us; and the legitimate inference is, that it will be alike operative in the future—ever eliminating the inferior, and establishing the superior on a higher and broader basis. This is nature's universal and irrevocable decree—the race to the swift, and the battle to the strong.

The inferior succumb and the superior succeed, though the inferior may seem to have a longer term of existence, and the superior a shorter in proportion to their higher organisation. We say *seem to have*, for as yet the palæontological evidence is too scanty to warrant a dogmatic conclusion; although what evidence we have points the fact of a shorter duration, geologically speaking, for the higher types of vitality, and longer for the lowly and less highly organised.

X. The last subject to which we shall refer is *the influence geology has exercised on modern belief in all that relates to the universal and incessant operation of*

Natural Law. All that geology has discovered in the waste and reconstruction of the crust, in the incomings and outgoings of life, in the ascension from lower to higher forms, and generally in the whole history of the world, proclaims the unerring and unbroken operation of Law and of Order. No revolutions, no breaks, no interferences—nothing save the stately and solemn evolution of things, physical and vital, in accordance with a preordained and determinate plan—a plan whose order we may trace, and whose intention we may in some measure comprehend. This great teaching has year after year been carried into other branches of study, and may now be said to pervade the whole tone and spirit of modern philosophy. How important for science to know she is dealing with phenomena not the results of capricious chance, but of systems of causation whose order is fixed and whose outcome is certain! And what a gain too, socially and morally, to feel that life and all its surroundings are not the unconnected uncertainties of hap-hazard, but under the direction and control of unswerving law, whose methods we may ascertain, and with whose requirements we may conform!

The more fully this belief in the universality of Law can permeate the human mind, the more philosophical will become its methods of scientific research, and the more rational its lines of moral conduct. The olden belief in suspensions and interferences, whose times could not be predicted and whose results could not be inferred, invested all our efforts with feebleness and uncertainty; the modern conviction of Law emboldens our research, and holds out the hope of successful reality. Indeed it is not too much to affirm, that already this conviction has infused new strength into science, and will impart, as it becomes more generally accepted, greater beauty and consistency to life and morals —men walking most closely with God when they understand the laws of nature, and feel it their duty to conform to their requirements. So long as men believe in suspensions and special interferences, and think their importunities (which are for the most part very selfish) can have any influence in procuring modification of creative law, their conduct will be irregular and supine; but once they are convinced of the certainty of nature's methods, they will make rational effort to learn, and find it their happiness to obey.

Such are some of the more obvious teachings of geology, and some of the inferences deducible from these teachings. Geology is but a recent science, but though recent it has already done much to modify man's views as to the stability of the earth, the continuity and uniformity of natural forces, the gradual formation of the rocky crust, its inconceivable antiquity, the multifarious forms of extinct life, the gradual introduction of higher and higher forms, the likelihood of a kindred evolution in the future of still higher types of vitality, and above all, the universal operation of fixed and enduring Law. Like other opinions running counter to olden beliefs, these teachings have met with much opposition, and been the cause of many an angry conflict; but such has ever been the contest between the old and the new—such apparently the ordeal through which all innovations have to pass before their final acceptance or rejection. And it is good that it should be so, for by this process the new is winnowed and sifted, the true retained and the untenable rejected, while the old passes away without revolutionary shock or convulsion. And thus it is that the new ever retains so much of the old, and the old ever interpenetrates and influences the new. This is nature's method—transformation by degrees, and progression without revolution; and it were well that men in all their relations, civil, social, and religious, could temper their impetuosity and follow her example. If geology has established one truth more conspicuously than another, it is the gradual and continuous character of nature's processes. No breaks, no abrupt transitions, no sudden overturnings, but everywhere the slow and steady evolution of other and other aspects, physical and vital, whose summation in sequence constitutes the history of our planet.

Such, once more, are the teachings of geology, which, though of recent date, have deeply influenced the tone and tenor of modern speculation, modified former beliefs, and imbued philosophy more thoroughly with faith in the universal operation of natural or cosmical law. And if all this has been accomplished within little more than a century — even mainly within the current century—what, we may fairly ask, will the science have achieved in the centuries to come, when man, in the ascensive direction, shall have been endowed with higher powers, and animated by nobler aspirations?

II.—GEOLOGY: ITS ECONOMIC BEARINGS.

HAVING directed attention, in the preceding lecture, to the teachings of Geology and their influence on modern beliefs, in all that relates to the incessant nature of terrestrial change, the uniformity of the forces producing these changes, the interesting record these forces have left of their operation in the rocky crust of the globe, the incomprehensible time involved in this record, the exuberance and variety of extinct life, the gradual ascent, in time, from lower to higher forms of vitality, and the fair inference of the future continuity of this ascent,—we now turn to the economic or industrial bearings of the science. Whatever may be the opinion of the truth or importance of its scientific teachings—and these may long be varied and conflicting enough—there can be no difference as to the substantiality and increasing value of its practical results. They meet us at every turn in the arts and industrial processes of everyday life, in the increased facilities for travel and commerce, in the greater comforts and amenities of society; and the more that civilisation advances, the higher the importance they assume.

In his savage or nomadic condition man draws but little from the crust of the earth. A few stone tools and implements, and here and there a personal ornament—and these, like gold and precious stones, picked up from the surface—are all he seeks, or seems to desire. Seams of coal may crop out beneath his feet, but he never seeks them as fuel wherewith to feed his fire; veins of ironstone may appear in the cliff overhead the cave he inhabits, but he never dreams of converting it into metal, wherewith to fashion a spear or to tip an arrow. To him the wood, the bone, or the stone comes readiest, and he rudely shapes them to serve his requirements. As he begins to till the ground, seek a more durable home than a wigwam of wattles, and settle down in stationary communities, he casts about for tools and implements harder, tougher, and more durable than those of wood, bone, or stone; and having discovered the metals, he acquires a new mastery over the opposing forces of nature, and rises proportionally in the scale of civilisation.

The more civilised he becomes, the more he draws from the earth—all his stones for building and decoration, his fuels, lighting-materials, metals and metallic ores, fire-resisting substances, grinders, whetters, polishers, pigments, gems, and precious stones being obtained from the rocky crust. Indeed the utilisation of the minerals and metals may be taken as the standard of civilisation, so indispensable are they to all the arts and processes which we associate with power, comfort, elegance, luxury, and refinement. Without these treasures modern civilisation in all that relates to tools, implements, machinery, steam-engines, railways, steam-ships, and telegraphs, would have been impossible; and generation after generation they are being more extensively extracted and more variously utilised.

In this way it becomes of prime importance to know where these substances are to be found, how they occur, in what abundance they occur, and with what facilities they can be procured. For this purpose we must draw upon our knowledge of the structure of the earth; hence the importance of geology in all it has ascertained respecting the successive rock-formations, their areas, composition, thickness, inclination of strata, faults, dykes, veins, and other phenomena. The earth is a great storehouse of wealth, but this wealth is not scattered at random, and it requires geological skill to determine at once its place, position, abundance, and accessibility.

The first great duty of the practical geologist, therefore, is to map out and section the various formations with the greatest possible precision—ascertaining their areas, thicknesses, nature, and alternation of strata, and the dip or inclination at which they lie. In this way their economic value can be determined, and the miner can proceed with some degree of certainty with his operations, which are often of an expensive, difficult, and dangerous nature. The value of such mappings is now sufficiently appreciated, and almost every civilised country has either completed, or is busily proceeding with, its geological survey. Nor is it merely the rock-formations, properly so called, that the geologist delineates and describes; he takes cognisance, in like manner, of the soils and superficial accumulations upon which our crops, pastures, and forest-growths are more immediately dependent. Certain plants affect particular soils: the forest-tree that grows luxuriantly on one kind of soil would dwarf and die out if transferred to another. All soils are not naturally alike fertile, for want of certain ingredients, but may be rendered so by admixture of other soils which contain these ingredients. Indeed it is not too much to assert that the admixture of soils—only yet beginning to dawn on the agricultural mind—would create quite a revolution in the farming and forestry of the world,—the soil best fitted for any particular crop being, as it were, created at once in an efficient and permanent form, thus minimising the risk of climate, and aiding the effort of the plant to reach its maximum growth and maturity. From this point of view, the mapping of soils according to their characteristics is as important as the mapping of the rocks which underlie them. Such twofold surveys are of vast value to civilised nations, showing at once the nature, extent, and accessibility of their mineral wealth below, and the richness and fertility of the soils that overlie them. Commercially, the more man knows of the geology of the world, the wealthier and more powerful will he become.

But while this knowledge is of universal importance, it is of special value to those who have professionally to deal with the products of the earth in their economic or commercial relations. The farmer, for instance, who knows the nature of his soils and subsoils, and of their underlying rocks, is surely in a better position to correct their deficiencies by admixture, by draining, and manuring, than one who cannot discriminate the nature of these soils, or detect their deficiencies. The elements of fertile admixture may lie within the same farm; the defects in composition may be corrected by the application of appropriate manures; but how can the farmer obtain this needed information save through a geological acquaintance with the nature of the materials he has to operate upon and apply? "Let him obtain it from the geologist," say some, "and apply it empirically." So far good; but infinitely better that the agriculturist knew something of the matter himself, and could separate the wheat from the chaff of his scientific advisers. There is no mystery in science—nothing that a mind of average ability, with the same effort devoted to the ordinary affairs of life, could not soon master and learn to apply.

Again, as the worth of an estate depends not only on its agricultural capabilities, but also on its mineral value, the land-valuator who is unable to determine the character of its soils and subsoils, and is ignorant of its mineral structure, can never do justice to his client. A knowledge of the geological structure of an estate is not less necessary to fixing its real value than a knowledge of its various soils and climate; and it is often for want of this knowledge that estates are either sold under their value or bought at unremunerative prices. Every mineral, its nature, abundance, and accessibility, should be carefully noted down; for, in the rapid progress of the arts, the substance which seems worthless this year may be utilised and become of value in the next. The current century has witnessed the application of substances which our forefathers regarded as rubbish; and who can set bounds to human invention and discovery? At the present day, when farm-produce meets so ready a market, and the minerals and metals bring such high prices, no estate should be bought or sold without a thorough survey, alike of its surface capabilities and of its mineral stores; and this cannot be done with any degree of satisfaction without appealing to the mineral surveyor as well as to the mere agriculturist. In most instances a mineral survey would cost less than the salesman's commission, while it would give confidence to exposer and purchaser that neither were running risks beyond the contingencies of fair and prudent negotiation.

Again, take the case of the architect who has to deal with beauty and durability of structure without, and with elegance and decoration within. The beauty and durability of a building-stone, and the facility with which it can be obtained and dressed, is of prime importance in architecture. The stone which will keep its colour in the open country may not do so in the smoky city; and the rock which will resist the action of the weather in its normal state may waste and crumble down under the carbonated atmosphere of the manufacturing town. Nor is it structure and decoration alone that call for the assistance or suggestions of the geologist. The mortars, the cements, and concretes of the builder are yearly assuming a greater importance and receiving a wider application ; and as the component materials of these are all drawn directly from the earth, geology comes in with important information to the manufacturer, indicating the nature and abundance of the limestones, and sands, and gravels with which he has to operate. It is ignorance on this point which often causes the builder to bring from a distance materials which could be obtained of equal quality and at a cheaper rate in his own immediate locality. It is also a want of knowledge on this head that permits the manufacture of hydraulic cements, while limestones of natural hydraulic energy lie unknown and neglected.

In the next place, take the case of the civil engineer who has to plan and lay down roads and railways, to execute tunnels and cuttings, to excavate docks and harbours, to erect piers and breakwaters, to deepen and widen tidal rivers, and bring in water-supplies to towns. Not a step can be taken in any of these important operations without coming in contact with geological phenomena—not a plan can he lay down which does not depend more or less on a knowledge of rocks and rock-formations. It is true he may obtain information from geological maps and from professed geologists; but even with this aid, his work will be executed with feebleness and uncertainty compared with that of one who can discriminate the geological structure of a country for himself, avoid its difficulties, and utilise its products.

Once more, and we come to the mining engineer—whether working among stratified rocks for such products as coal, ironstone, limestone, and fireclay, or following veins and lodes in search of the metals and metallic ores. In either case some knowledge of geology is indispensable; and although it is true that mining was largely followed ere geology had shaped itself into a science, yet the *practical skill* of the miner in dealing with successions of beds, with dykes and dislocations, and with kindred phenomena, is geology of a kind, requiring the noting of facts, and the drawing of generalisations, not less real and serviceable than the deductions of the *theoretical* geologist. The wider, however, the geological knowledge of the mining engineer, the better will he be able to cope with the difficulties that present themselves in his arduous calling. His services may not always be restricted to the same district. His advice may be sought for in other districts, where there are other rocks, other successions, other dislocations and appearances; and he will be but poorly prepared to deal with these unless he is, in some measure, acquainted with the general principles of geology. Besides, new substances are yearly being utilised, and it is the duty of the mining engineer to keep pace with this progress, and to see that nothing in his workings be left unnoticed or unused. While every region of the globe is being ransacked to supply the mineral and metallic requirements of Europe and America, the mining engineer may safely calculate on a wider field for his services—and these services can only be valuable and reliable in proportion to his scientific knowledge of the subjects with which he has to deal.

Or take the emigrant and settler in a new country. One may be pleased with the situation, scenery, and soil of one district and settle down there; another acquainted with geology may choose a poor, uninviting tract, satisfied that coal, iron, or other mineral underlies it. As years roll on, and the country becomes populous, the one location will never bring more than its surface or agricultural value, while the other may have risen in value a hundred-fold through the development of its minerals and metals. There are few things so valuable to the emigrant as some scantling of geological knowledge.

But it is not alone to the farmer, the land-agent, the builder, the civil engineer, or the mining engineer that some acquaintance with geology is of importance. Its applications to the arts and manufactures are numerous and direct—to the fictile arts of the potter and glassmaker, to the manufacturer of mineral pigments and dyes, to the metallurgist and chemist, to the lapidiary and jeweller, and even to the mechanical engineer and machinist. The potter and glassmaker derive all their clays and sands from the earth; all our mineral pigments are directly or indirectly derived from the same source; so likewise are all our metals, whether native or as ores; and so likewise our fossil fuels and lights—our millstones, grindstones, and whetstones—our salts and saline earths—our gems and precious stones. In fine, there are few of the arts and manufactures which do not less or more depend on the mineral or metallic treasures of the earth; and surely some acquaintance with the composition and structure of that earth, so that the place of those minerals and metals may be known, their abundance ascertained, and the facility of obtaining them be determined, cannot fail to be of advantage to those who have to fashion and fabricate them into objects whether of utility or ornament.

It is not required of practical men to go deeply into the theories of geology, for that is impossible, and useless even if it were possible; but surely an intelligent acquaintance with the nature and origin of the materials they are daily manipulating cannot be otherwise than a gain and a source of satisfaction where the thought of pecuniary gain is altogether out of the question. Civilisation depends in a prime degree upon our mastery over the opposing forces of nature, and we cannot conquer any force or power save by the application of a superior one. Physically, man is weak and helpless; armed with implements and machinery he becomes a Titan. Without tools and machinery, man has to succumb to the forces of nature; equipped with these they become his willing servants—turning his wheels, raising his weights, wielding his hammers, lessening his labours, and carrying him over land and sea with unparalleled celerity. Our most important implements and machinery are derived from the mineral world; the heat that sets them in motion is derived from the same exuberant source. How direct, then, our civilised dependence upon the earth and a knowledge of its mineral and metallic treasures! How important to every art and manufacture to learn something of the nature and character of the source from which they are procured!

We say, how direct our civilised dependence upon the earth and a knowledge of her mineral and metallic treasures! It is these treasures that draw men to certain centres, and convert them into busy hives of human industry, while the surface fertility of a country maintains but a scanty and stationary population. The gold-fields of Australia did for that country, in a few years, what a century of agriculture would have failed to accomplish. The mineral wealth of California has conferred on the Pacific side of America, in one brief generation, a population, an industry, and a commerce almost rivalling that which the Atlantic side has taken a couple of centuries to attain.

Or turning to our own island, look at Cleveland, which thirty years ago was one of the most remote and solitary tracts in the north of England, with here and there a little homestead scattered over its pastoral expanse, — witness it now, after the discovery and utilisation of its ironstone! A busy centre of human industry, studded with blast-furnaces, traversed by railways, resonant with the roar of the forge and the clank of endless machinery. Its homesteads have become villages, and its only village has grown into a large and populous seaport. Middlesborough, with its docks, shipyards, and factories, promises speedily to become to the Tees what Sunderland is to the Wear, and Newcastle to the Tyne. And all this the result of one or two beds of ironstone, not peculiar for their richness or quality, but easily obtained, and lying in proximity to the coal-field of Durham.

Or take Barrow-in-Furness, which twelve or fourteen years ago was an insignificant seaside village with one or two hundred inhabitants, and which is now a thriving seaport of forty or fifty thousand, with its iron-works, docks, breakwaters, and steamships in direct communication with every part of the country. This has not arisen from any amenity of the district though pretty enough, but directly from the numerous deposits of hæmatite which are peculiar to that part of North Lancashire. It is the same with every other mineral district—with South Wales, with Staffordshire, South Yorkshire, Durham, and Northumberland, Lanarkshire, and Ayrshire. The teeming thousands and miscellaneous industry of these districts is the direct outcome of their coal-fields rich in coal, ironstone, limestone, fire-clay, and other minerals. Without these subterranean treasures, those districts, now thronged with large and populous towns, would still have been occupied by a few scattered hamlets and homesteads.

As formerly noticed, certain minerals are peculiar to certain formations, or at least occur more abundantly in some formations than in others. This generalisation of theoretical geology has been of immense practical importance, often preventing ruinous outlay and bitter disappointment. Formerly the search for coal and other minerals was made in localities where the slightest acquaintance with geology would have told the search was fruitless. Thousands, for instance, have been spent in boring and sinking for coal in the Old Red Sandstone—a formation in European countries utterly void of that mineral. Need we point to the abortive attempts in Strathearn and Strathmore as proofs of this ignorance and persistent perversity?

Again, geology affirmed the continuance of the carboniferous formation under the New Red Sandstone, and gave reasons for the affirmation. Some proprietors received the assertion with doubt and distrust, and would not be persuaded to make trial; others, convinced by the reasons assigned, unhesitatingly sunk their shafts, and now they are reaping the reward of their confidence and enterprise.

Further, the occurrence of water in any stratified formation is a thing entirely dependent on the structure and texture of the rocks of that formation. Are the rocks retentive or water-bearing, are they fissured and faulted, or intersected by dykes or other obstructions? This is strictly a matter for geology to determine, and yet, in ignorance of it, thousands of wells have been sunk, or borings put down, without obtaining a drop of water. Need we point to the futile attempt of your own Convalescent Hospital in the greenstone of the Corstorphine Hills; to the efforts of a late Linlithgowshire proprietor on the north side of an intersecting dyke, while a few yards to the south of it water was obtained in abundance; or to the case of Dundee, where, for a similar reason, borings on the north-east of the town yielded a copious supply, while expensive attempts to the south-west failed to secure a single gallon?

Once more, take the case of coal-mining in an igneous and convulsed district. Formerly, when beds of greenstone occurred in the field, the miner lost heart and abandoned the search as hopeless. Now that geology has shown that certain greenstones are interbedded overflows, he sinks his shaft through them, whether 10 feet or 100 feet in thickness, confident the seams of coal will lie untouched and undisturbed beneath. These instances will suffice; but numerous others could be given, to prove most convincingly the importance, in an industrial point of view, of the deductions of geology. In a country like Britain, whose mineral wealth is so varied and whose rocks are so complicated, whatever tends to the accuracy and speedy completion of her geological survey is worthy of the warmest encouragement.

The application of the minerals and metals to the industrial purposes of life is yearly on the increase, and every civilised nation is striving to discover its geological wealth and turn it to advantage. This is convincingly illustrated by the economy of a coal-field. Fifty years ago the output of coal in the British Islands did not much exceed 50 millions of tons—now, it is little short of 130 millions! As with coal, so with every other substance in the carboniferous system. These substances come under six great categories—sandstones, shales, fire-clays, limestones, ironstones, and coals; and each of them has shown a corresponding increase, both in the quantity extracted and in the purposes to which they are applied. Let us look at them in detail.

Sandstones, according to colour, texture, and durability, are raised for building, for decoration, paving, millstones, grindstones, glass-cutting, firestones, and for various other purposes. For illustration of this, need I point to your own city, as well as to the other great towns situated on and in proximity to our coal-fields. Edinburgh owes much of her attraction to her natural site and surroundings, but that attraction is intensified by the beauty and durability of her building-stone, which is fitted for every requirement of sculpture and architecture,—thus giving a substantiality and finish to her streets and squares unrivalled by any other city in the kingdom.

Shales, which thirty years ago were next to worthless, are now largely and variously utilised according to their respective qualities—some for the preparation of alum, others for copperas, and those containing nodules of iron pyrites occasionally in the manufacture of sulphuric acid. But the chief and most remarkable utilisation of the bituminous sorts is in the distillation of paraffin and paraffin-oil, and their various by-products. Sixteen or eighteen years ago these shales lay utterly valueless and unheeded; now they bring handsome returns to their proprietors, and the poor moorland estates on which many of them occur have more than trebled their value. There has been no triumph of chemistry so decided as the utilisation and distillation of these shales—evoking products at once useful, elegant, and brilliant, from what in former ages was only a dark, fetid, vegetable sea-mud.

Fire-clay, which at that time was manufactured at a few places into fire-bricks, is now fashioned into innumerable articles of utility and ornament at scores of works in Staffordshire, Wales, Durham, Lanarkshire, Fife, and Mid-Lothian. There is no substance which of late has assumed a greater importance or been turned to so many uses. Not only has it been formed, as its name imports, into fire-bricks, but into gas and chemical retorts, building bricks, vases, and garden ornaments, and, above all, into sewage or sanitary pipes of unequalled fitness and durability. As a material for the drainage of towns it stands unrivalled, being easily shaped to any course however tortuous, affording no lodgment for vermin, flushed by the merest trickle of water, and thus kept sweet and clean, while other material would become mud-logged and noisome.

The *ironstones* of the carboniferous system—clay-band, and blackband—lying in close proximity to the coals which smelt and the limestones that flux them, are especially sought after and utilised. It is not that there is a scarcity of ironstone in other formations, but that these blackbands and claybands are associated with the coals, limestones, and fire-clays indispensable to their reduction. In every coal-field where they occur they are greedily sought after; and few substances have exerted such an influence on the population and industry of our country. Wherever they have been found, blast-furnaces and villages spring up, with iron factories and all the other adjuncts of a busy mechanical industry.

The *limestones* are also turned to numerous and important uses — as building-stones and marbles, mortars and cements, a flux for ironstone, besides being employed in agriculture, in bleaching, tanning, and numerous minor purposes.

And lastly, the consumption of *coals* of every variety—household coal, steam-coal, furnace-coal, coking-coal, gas-coal, and oil-coal—is rapidly on the increase, and they are so essential to the arts and manufactures as well as to domestic comfort, that it is difficult to see how British industry could be carried on without them. They are the mainstay of our mechanical supremacy, and the animating spirit, if we may so speak, of all the arts and manufactures by which our teeming millions are sustained.

Besides these six staple products—sandstones, shales, fire-clays, limestones, ironstones, and coals—there are minor substances, such as ochre, lead, silver, zinc, and antimony, all derived from the carboniferous system, and all giving employment to thousands, and conferring wealth and comfort on the nation. In fine, our mechanical and commercial supremacy depends in a great measure on our coal-fields: our steam-engines, steam-ships, railways, telegraphs, and endless machinery are their direct outcome, and would have been simply impossible without them.

As with the carboniferous system, so with every other system in the crust of the globe. There is always some substance that can be turned to account in the multifarious wants of civilised existence. If not iron, and coal, and fire-clay, there may be stones for building and decoration, for slating or paving, for mortar and cements, for milling and grinding, for whetting and polishing, for the manufacture of glass or pottery, for the production of pigments and dyes, or for the preparation of mineral manures. Or, where these are not available, there may be gems and precious stones, metals or metallic ores, or even mineral springs of therapeutic value and celebrity. An efficient mineral spring, conveniently situated, is even more important to a country than a seam of coal: in course of time the coal gets exhausted, while the spring—*e. g.*, Buxton—flows freely and unchanged for ages. There is no formation which does not yield some substance or other which human ingenuity may not utilise and turn to advantage. And there is no substance, however waste and worthless now, that some day or other may not be turned to use, and assume a commercial importance. The refuse-heap of our fathers has more than once become a fortune to the present generation. The wider, therefore, geology can extend her researches, the more numerous and varied the substances she places at the disposal of man.

This is well illustrated by the British Islands, whose formations have been more minutely investigated than those of any other country, and whose economic minerals are therefore better known. Every district has been examined, and every product more or less minutely described. Britain is highly favoured in having representatives of every geological system, from the most ancient to the most recent, and these conveniently placed, and appositely distributed. A glance at the map will show that there is no formation occupying a wide area to the exclusion of the others, but all of moderate size and readily accessible. It is this variety and accessibility of formation which has conferred on her her mineral wealth, and which has moulded in a great degree the pursuits and industry of her people. Britain is eminently a mining country—has been so from a very early date—and the necessities of her present industry compel her to maintain her position. The annual value of her mineral and metallic produce exceeds seventy millions; but, large as this sum may appear, it gives no adequate idea of the power, wealth, comfort, and general amenity which this produce confers on her inhabitants.

To arrive at some conception of this we have only to imagine what would be our condition in this inhospitable climate without our cheerful fires, in these long winter's evenings without our brilliant lights—without our machinery which lessens toil and increases production, without our railways which facilitates our travel and traffic, without our steamships promoting rapidity of transit, and without our telegraphs giving us almost instantaneous intelligence of what is taking place in other countries, and bringing us within speaking-distance, as it were, of our friends at the farthest ends of the globe. Our forefathers got on very well without any of these appliances, you may say, and rejoiced in their "merrie

England;" but we question much whether the most enthusiastic admirer of these olden times would willingly exchange the amenities of the present for the merriment of the past. The poorest peasant has now comforts and amenities at his command, if he could only use them aright, which the proudest baron of old could not possibly possess. And this mainly through the development of the mineral and metallic wealth of our Islands.

But while we boast of this mineral wealth, let us ever remember that, unlike the surface soil, which is improved by use, the mineral, when once extracted, is gone, and for ever. With the increased and ever-increasing consumption of recent years, the time must come—and sooner than most of us calculate—when these minerals and metals shall have been exhausted—the last furnace blown out and the last fire extinguished. We will not attempt to lift the veil from so gloomy a future, but would rather suggest for the present, that each and all of us should practise the strictest economy in their use, devise means for lessening their consumption, invent new substitutes, call in the use of auxiliary substances, and, above all, prevent wasteful means of working, so that if we cannot prevent their exhaustion, we may at least postpone the period to a more distant day.

Such are the scientific teachings and economic bearings of geology—such the interest of its scientific problems and the value of its industrial facts. Geology is but a recent science—so recent that all its legitimate work may without much exaggeration be limited to the current century; but though recent, it has already taken a prominent place among the natural sciences, and exercised a decided influence on other and different lines of thought. It has shown that our globe through all geological time has been in a state of incessant change—the waste of old rocks and the reconstruction of new; it has shown that the forces producing these changes have ever acted in a similar manner, and are stable and enduring as the solar system, upon which they are dependent, is stable and enduring; it has proved the unbroken continuity of nature, and shown that we may reason with certainty from the present to the past; it shows that the result of these agents as recorded in the rocky crust implies an inconceivable lapse of time, which can only be dimly indicated by ages, and periods, and cycles; it has proved that numerous as are the forms of life now existing, they constitute the merest fraction of the forms that have lived and passed away; it has shown that the lower and simpler forms preceded the higher and more complex in one long line of ascent; and as all the forces of nature are acting as vividly as ever, it presumes that the future will be marked by a similar ascension. Throughout the whole of geological time—and beyond that limit it declines to hazard an opinion—it has seen nature acting in a regular and uniform manner, and therefore believes that the order of nature is in accordance with fixed and enduring law. Sustained by that belief, it sees nothing in creation whose manifestations may not be investigated, whose order may not be traced, and whose nature and causation may not hopefully be accounted for. In these teachings it has met with much and unmerited opposition ; but the conflict is now nearly over, and the time is fast approaching when the legitimate deductions of geology will be as fully accepted and appreciated as those of the earlier science of astronomy. And then the wonder will be why bigotry was so blind, and dogmatism so intolerant, as not to perceive what was so plain, and not to accept that which was so catholic and important.

Turning from its scientific aspects and inferences to its economic bearings, we find it busily scrutinising the materials of the earth, noting their position and order, and trying to determine their properties and uses. Year after year it broadens its knowledge of these materials, discovers new uses and appliances, and thus adds to the power, the comfort, and elegance of civilised existence. And the more we can increase man's physical power and comfort, the more we lengthen the lever by which he can raise himself to a higher stage of intellectual and social attainment. So closely is the physical of our existence interwoven with the intellectual, that whatever can facilitate the wellbeing of the former, strengthens, enlarges, and renders more subtle the grasp of the latter. We have seen how much man's civilisation depends upon the minerals and metals; and as these do not occur at random, the science that can lead to the determination of their place and mode of occurrence can never fail to excite our interest, or meet with an adequate appreciation. All knowledge of nature is good, but that is doubly so which, while it gratifies and improves the mind, can administer at the same time to the wants of our physical nature. And this is especially so with geology, which, while it reveals the long and varied history of our planet, directs us, at the same time, to those minerals and metals whose applications are so intimately interwoven with the character and progress of our modern civilisation.

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